Combining Advanced DWR and Surface Observations and Bin Microphysical Modeling to Enhance Frozen Phase Precipitation Process Understanding

Branislav M. Notaros[1], V. N. Bringi[1], Andrew J. Newman[2], Gwo-Jong Huang[1,3], GyuWon Lee[3], and Dmitri Moisseev[4,5]

NASA PMM Meeting – 11 October 2018

NASA PMM Grant NNX16AE43G

[1]Department of Electrical and Computer Engineering, Colorado State University
[2]National Center for Atmospheric Research
[3]Center for Atmospheric REmote sensing (CARE), Kyungpook National University, Rep. of Korea
[4]Institute for Atmospheric and Earth System Research, University of Helsinki
[5]Finnish Meteorological Institute, Helsinki Finland

COLORADO STATE UNIVERSITY

Outline

NASA NCAR UCAR

- Project Background
  - Motivation
  - Case study overview
- Results
  - New SR(Z_{Ku}, DWR) development
  - WRF model-observation comparisons
- Summary

Project Motivation

- Frozen phase microphysics is a complex blend of many processes
- Representation in numerical models still needs much refinement
  - Uncertain process representation and rates
- High quality observations are still relatively sparse

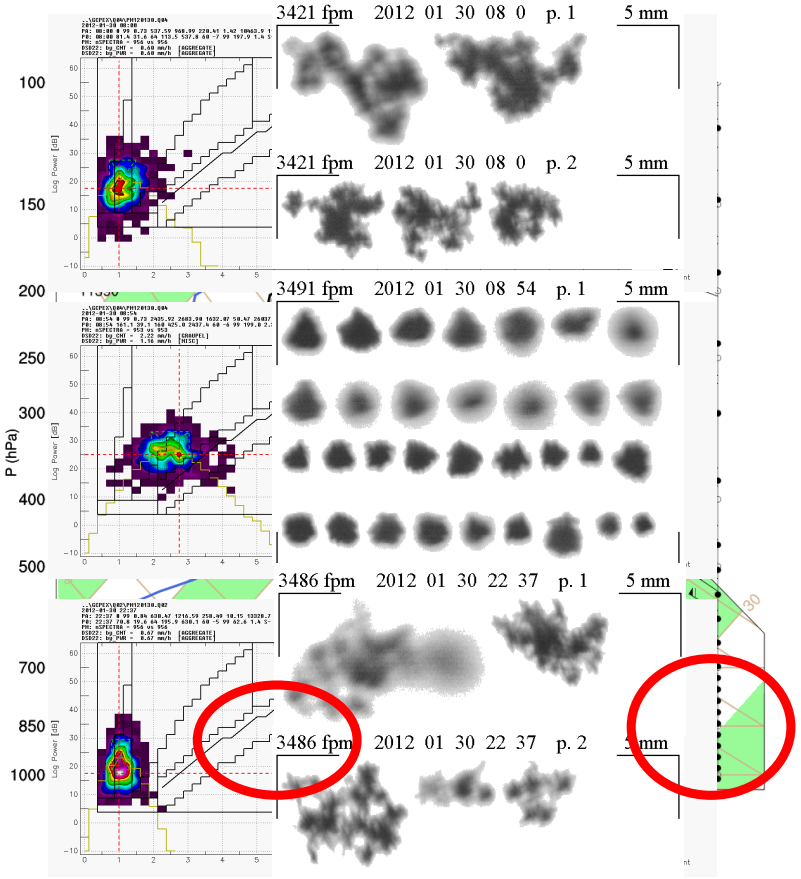
- GCPEx had many advanced in situ and remote sensing observations for ground validation and microphysical studies
- Proposal goal: Use 2DVD, PIP, scanning radars (e.g. D3R), POSS, MRR, etc. for comparisons to WRF bin microphysics simulations
- Atmospheric models and microphysical schemes need to be confronted with high quality observations
  - Identify areas needing improvement and test alternatives in microphysics scheme

Project Motivation

- GCPEx
  - 30-31 January 2012
    - Lake effect banded snow followed by large-scale uniform light snowfall events in 36-hr period
    - CARE & Huronia

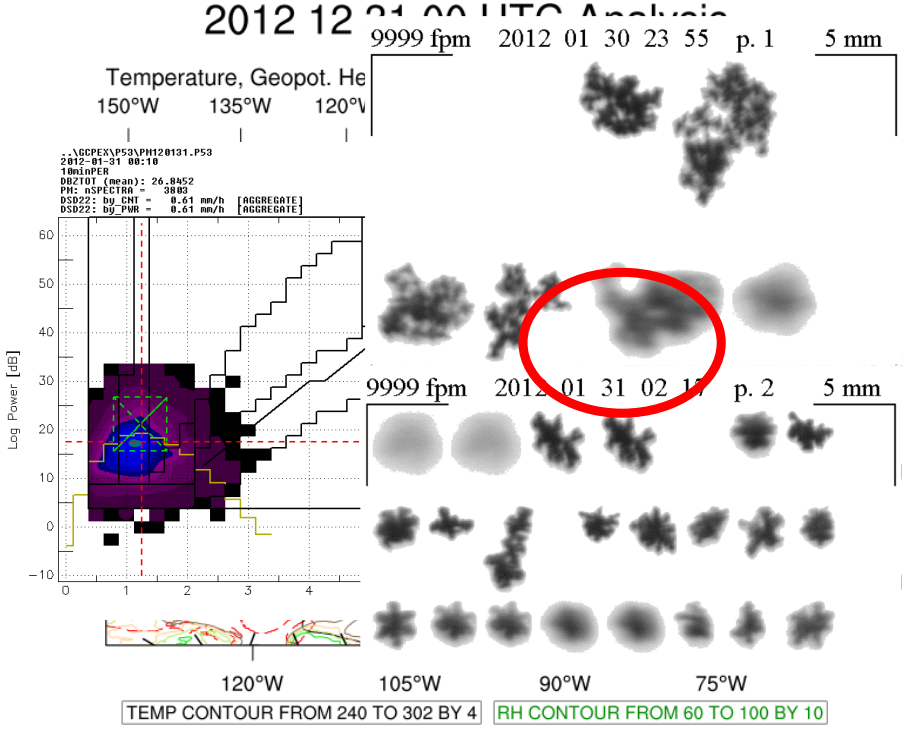
Case Study Overview

- Lake effect on 30 January 2012
  - Cold WNW flow across Lake Huron
  - Lake temps ~2 ºC, 850 mb -15 ºC
  - Dendritic growth zone at 1 -1.5 km
  - Alternating graupel and large aggregates
  - Riming likely throughout the event



Case Study Overview

- Synoptic snowfall on 31 January
  - Warm air moving up and over frontal zone (vertical motion and condensation)
  - Air temperatures ~ -10 to -15° C and good moisture supply in vertical motion layer
  - Dendritic growth, yet little riming



Results - Observations

- Developed new radar snow rate (SR) estimate using Z_h and dual wavelength reflectivity ratio (DWR)
  - D3R radar, 2DVD, Pluvio during synoptic snowfall event
  - Beginning to assess methodological uncertainty
  - Snowflake mass, fall speed, characteristic dimension, and scattering model

Characteristic	Option #1	Option #2
Mass	Böhm (1989)	Heymsfield and Westbrook (2010)
Fall speed	Huang et al. (2015),	Joanneum Research
Characteristic Dimension	Equivalent spherical diameter	Maximum dimension
Scattering model	T-matrix using soft spheroids with fixed axis ratios and quasi-random orientations	Liao et al. (2013) effective fixed density and oblate spheroid; fixed density of 0.2 gcm^{-3}

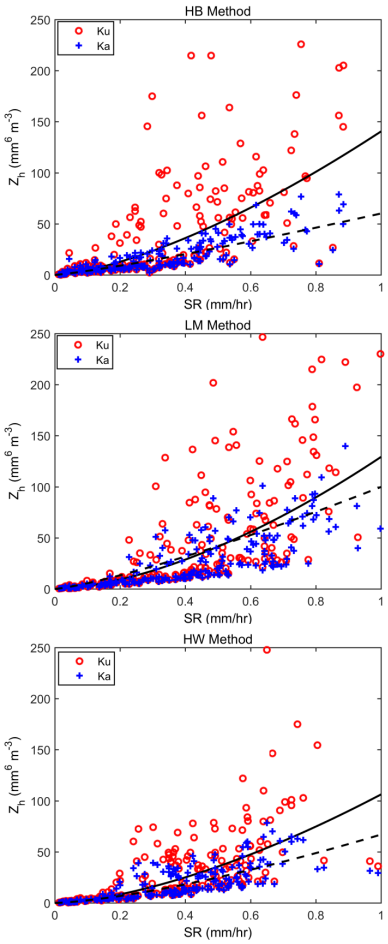
Results - Observations

- Developed new radar snow rate (SR) estimate using Z_h and dual wavelength reflectivity ratio (DWR) (at CARE site)
  - Choose three combinations from table:
  - **HB -** Bohm (1989), Huang et al (2015) fall speed and scattering model
  - **HW -** Heymsfield and Westbrook (2010), Joanneum fall speed, Liao et al. (2013) scattering
  - **LM –** Bohm (1989), Joanneum fall speed, Liao scattering

Characteristic	Option #1	Option #2
Mass	Böhm (1989)	Heymsfield and Westbrook (2010)
Fall speed	Huang et al. (2015),	Joanneum Research
Characteristic Dimension	Equivalent spherical diameter	Maximum dimension
Scattering model	T-matrix using soft spheroids with fixed axis ratios and quasi-random orientations	Liao et al. (2013) effective fixed density and oblate spheroid; fixed density of 0.2 gcm^{-3}

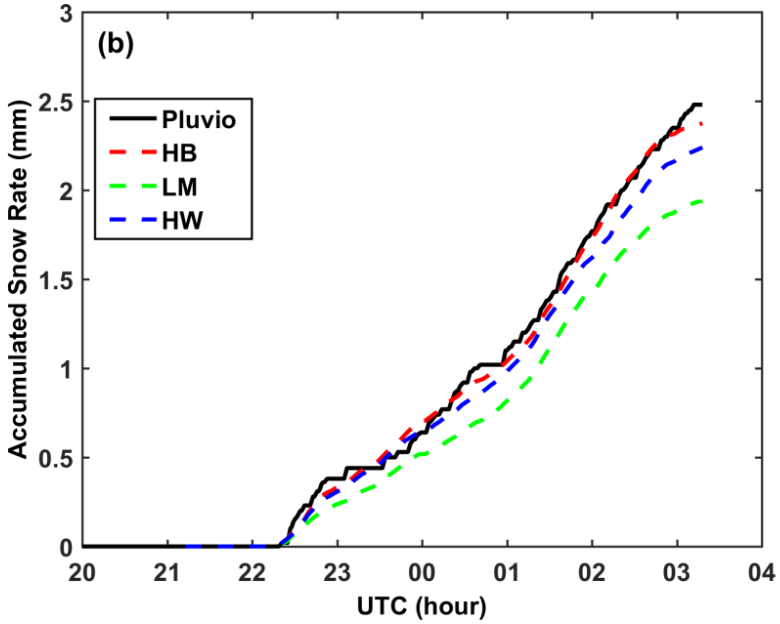
Results - Observations

- Comparison of the 2DVD derived DWR using **HB**, **LM**, and **HW** methods
  - **HB** compares best
  - However, the PSDs across methods are **not** exactly the same
- *Left panels* - 2DVD derived Z_h versus 2DVD measured SR, with Z-SR power-law fits, for Ku- and Ka-bands
  - Z_{Ku}-SR has much more scatter than Z_{Ka}-SR
  - We use Z_{Ka}-SR for single band retrievals
- *Right panels* - estimated SR using Z_e and DWR from 2DVD versus 2DVD SR
  - All biased high when SR<0.2 mm
  - **Including DWR reduces normalized variance of fit from Z_{ka}-SR from ~40-45% to ~30%**



Results - Observations

- Accumulation traces:
  - Z_{Ka}-SR relationships only
  - Final algorithm: radar SR estimated by combining SR(Z_{Ku}, DWR) and Z_{Ka}-SR when DWR ≈ 1
  - RMSE of accumulation timeseries decreases when including DWR
    - ~50% for **HB**

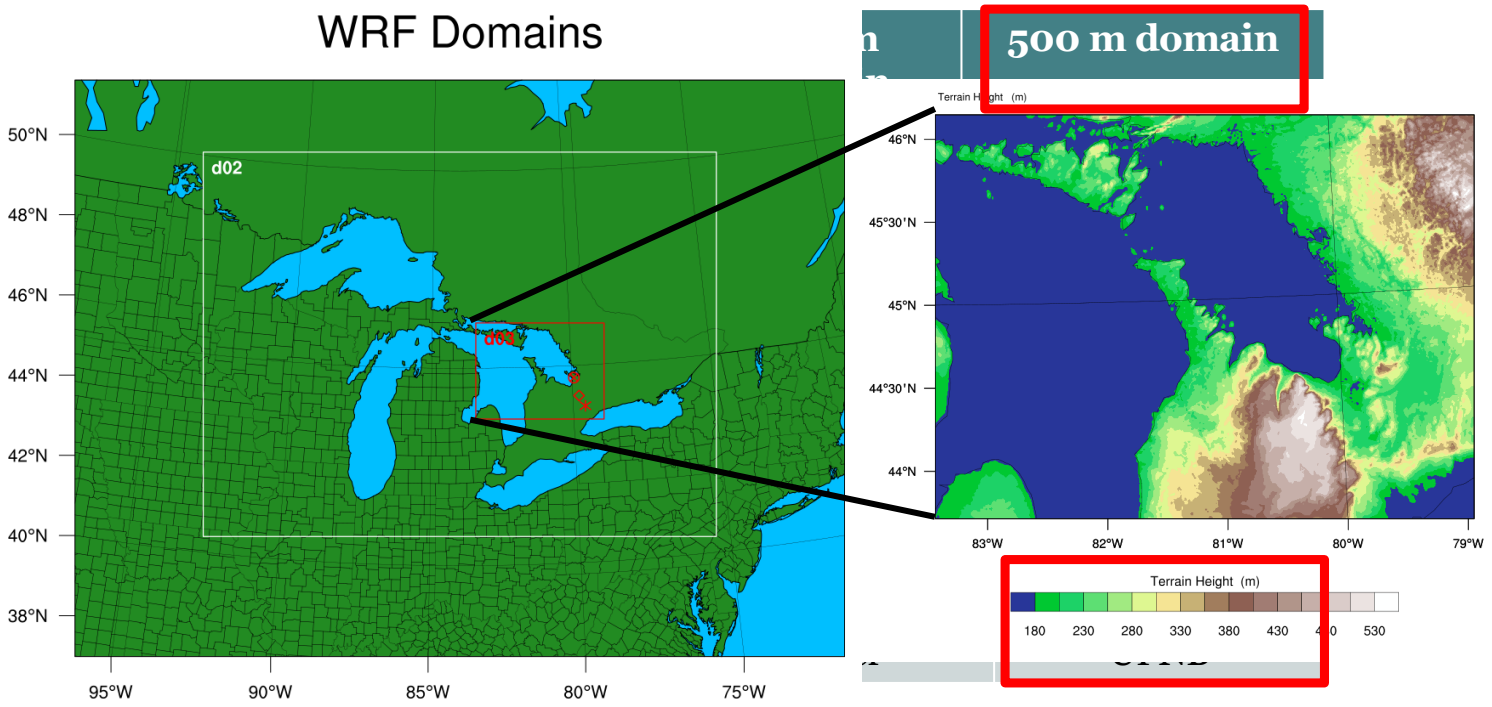


WRF Model-Observation Comparisons

- New SR(Z,DWR) and previous Z-SR relationships generate areal snow accumulation maps
  - Take home: Inclusion of DWR improves radar-SR fit and estimation as compared to reference gauge
  - One component of model-observation comparisons
- Multi-metric comparisons
  - More constrained identification of process and/or parameter deficiencies
  - Help prevent model overtuning – getting the right answer for the wrong reason(s)
- WRF using bin microphysical scheme

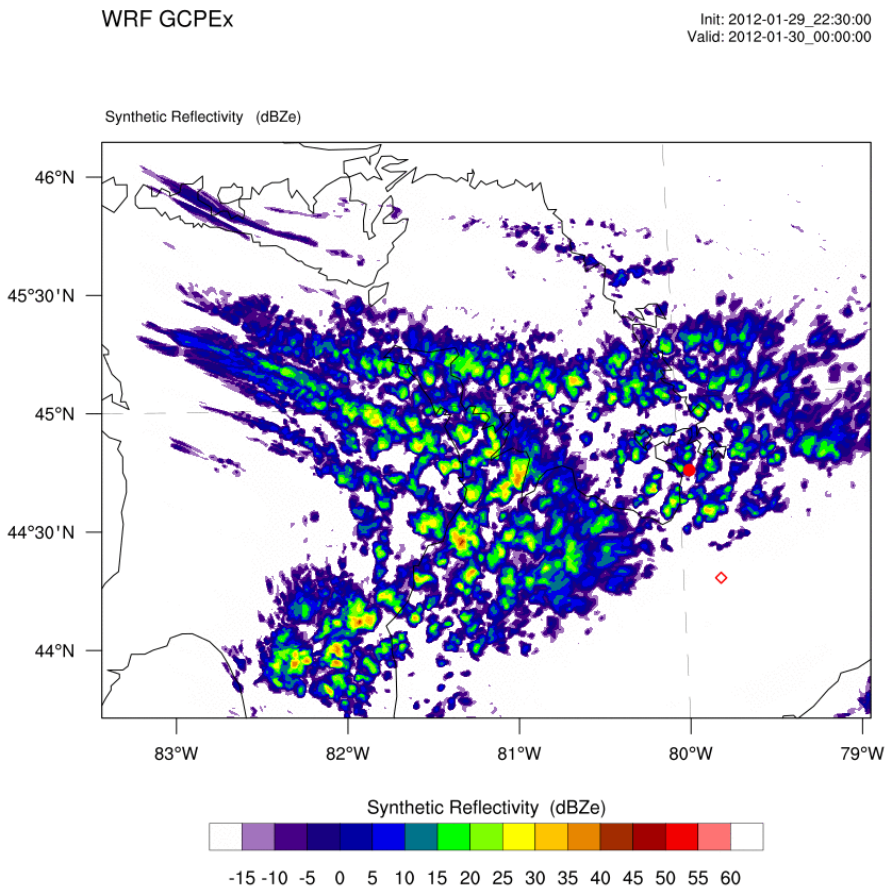
WRF Configuration

- WRF V3.7.1
  - Three domains



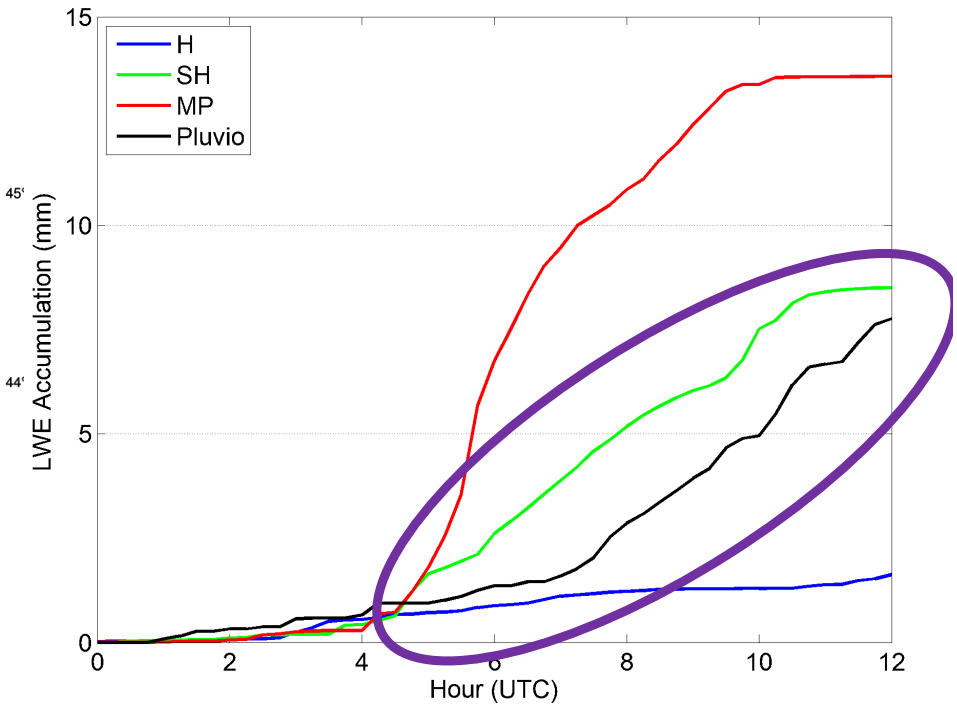
WRF Simulation

- Model analysis focuses on 500-m domain
- WRF produced linear bands to cellular lake-effect snow storm structure
  - Also made bulk microphysics simulations – no in-depth validation performed yet
  - Inclusion of PBL scheme at 500-m has large impact on simulation
    - Similar to Iguchi et al. (2012)



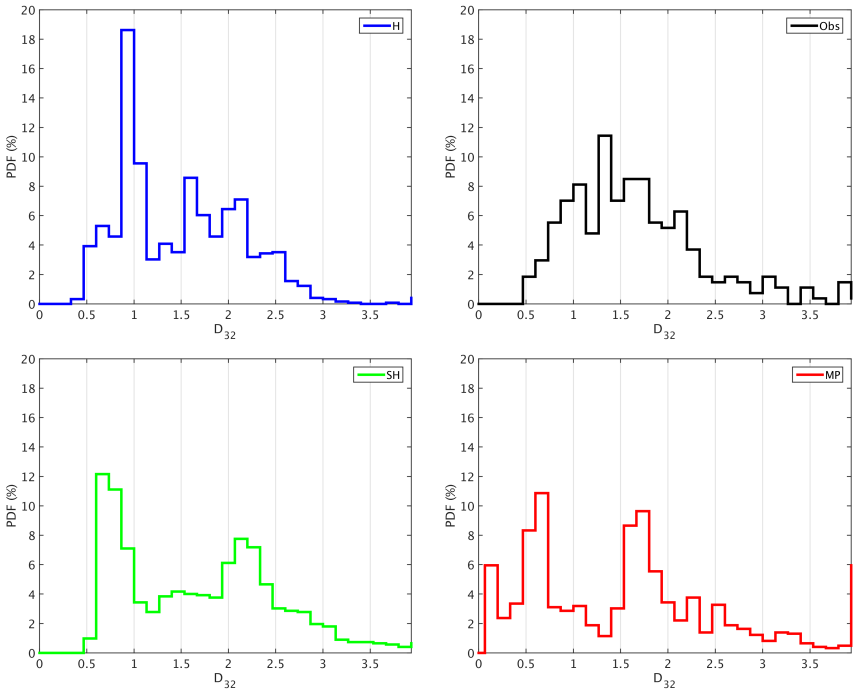
WRF Simulation

- Total Liquid Water Equivalent (LWE) accumulation at Huronia (H), South of Huronia (SH), and model Maximum Precipitation (MP)
  - Used as guide for similarity to observations
  - SH point is similar to observations
    - Accumulation rate and total amount



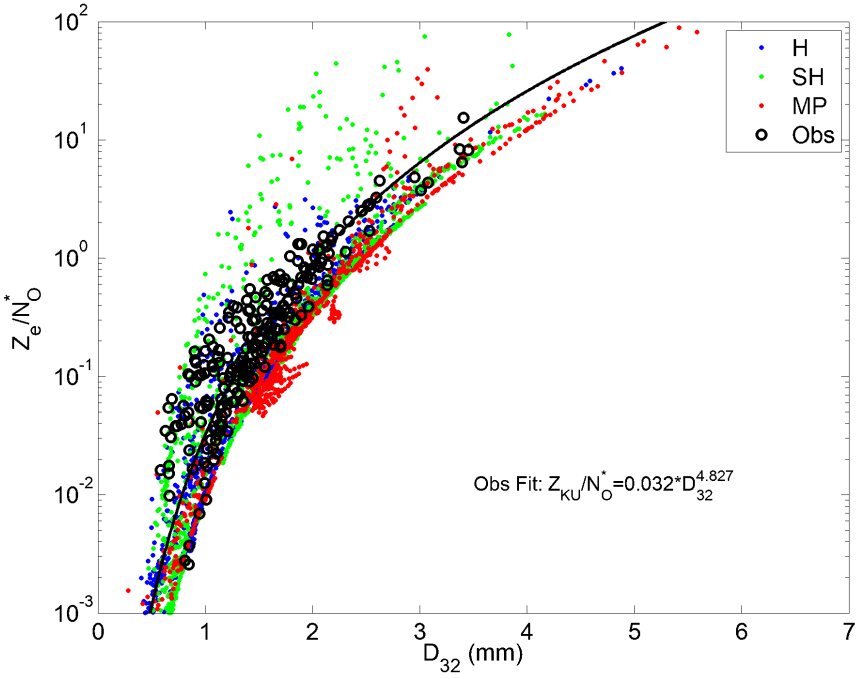
Model-Observation Comparisons

- Histograms of the third moment (M_3) to the second moment (M_2) of the PSD (D_{32})
  - Model reproduces maximum extent of observed D_{32} variability
  - Distribution is incorrect
  - Observations are unimodal while model is always bimodal
  - Microphysical or dynamical cause is under investigation



Model-Observation Comparisons

- Scatter plot of Z_e/N_0^* vs. D_{32} for observed and modeled data
  - Z_e is calculated in the similar manner for both model and observations
  - $N_0^* = (M_2)^4 / (M_3)^3 = (M_2) / (D_{32})^3$
  - Both observations and model data agree qualitatively with the theoretical relationship ($Z_e/N_0^* \sim D_{32}^5$)
  - Relatively independent of precipitation rate, useful way to synthesize and compare observations and model
    - Model m(D) relationship impacts comparison



COLORADO STATE UNIVERSITY

Summary

NASA NCAR UCAR

- Examining GCPEx 30-31 January 2012 lake-effect and synoptic snowfall event
  - Advanced observations permit more holistic investigation of winter precipitation events and model simulations
- Developed improved radar snowrate estimation using DWR - SR(Z,DWR) relationship
- WRF LES simulation of the GCPEx lake-effect snow event using the UPNB scheme reasonably captured the storm structure and precipitation pattern
- UPNB explicitly simulates evolution of PSDs and reproduced precipitation PSD close to the ground
  - Uncertain model-observation comparisons due to imperfect model simulation
- Z_e/N_0^* vs. D_{32} mostly independent of precipitation rate
  - May be a useful way to synthesize model data across domain
  - Discrepancies between modeled and observed data likely can be attributed to the fixed mass-size and terminal velocity relationships in the UPNB